CONSTRUCTION OF TWO MICROTUNNEL ACCESS SHAFTS USING THE CUTTER SOIL MIX (CSM) METHOD IN THE SAN JOAQUIN DELTA, CALIFORNIA

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Two microtunnel access shafts were constructed using the Cutter Soil Mixing (CSM) method in the San Joaquin Delta region of California, east of San Francisco. Unlike conventional slurry walls and diaphragm walls that utilize concrete, soil mixing relies on blending the soils in situ with a cement slurry to create a soil-cement wall. Cutter Soil Mixing technology utilizes two sets of vertically mounted cutting wheels rotating about a horizontal axis to produce rectangular panels of treated soil. Overlapping of the soil mixed panels enabled the construction of two circular shafts.

CSM panels were constructed to a depth of 29 m (95 ft) for the microtunnel jacking shaft and to a depth of 19 m (63 ft) for the microtunnel receiving shaft. The site presented several challenges, including the high depth of treatment, the variable nature of the alluvial soils, and the high water table.

This paper describes the CSM technique and presents the design, construction, quality control measures and advantages of using this method for this project.

INTRODUCTION

Project Information

The Contra Costa Water District (CCWD) Alternative Intake Project – Victoria Canal Conveyance Pipeline is located within the San Joaquin Delta region of California, west of Stockton and east of Discovery Bay. The project included an approximately 275 m (900 ft) long tunneled segment that crosses the Old River between Byron Tract and Victoria Island. The contract documents specified that the river crossing be made by microtunneling from a jacking shaft on Byron Tract to a receiving shaft on Victoria Island. As is common in the Delta region of California, the river is confined by levees and the river level is significantly higher than the typical elevation of the land to either side of the river.

The jacking shaft was located on the west slope of the western river levee at a relatively tight site within CCWD's Old River Intake and Pump Station facility. The receiving shaft was located in an open field about one hundred meters east of the eastern river levee.

Geotechnical Conditions

In general the site soils consist of thin deposits of peat and organic soils that are underlain by older alluvial soils to great depth. The alluvial soils include silt and clays (flood plain deposits) that are interbedded with sands.

The Geotechnical Baseline Report (GBR) for the project indicated that the soils at the jacking shaft would be primarily low plasticity, stiff to hard cohesive soils with a few relatively thin sand interbeds from the ground surface down to the tunnel elevation. These cohesive soils are underlain by a 3 to 5 m (10 to 15 ft) thick sand layer at the tunnel elevation, an approximately 6 m (20 ft) thick layer of clay just below the shaft bottom, which, in turn, is underlain by more permeable silts and sands.

At the receiving shaft, the soil profile consists of a meter or two of peat overlying a 3 to 5 m (10 to

15 ft) thick layer of sand, followed by stiff to very stiff clay to more than 9 m (30 ft) below the bottom of the shaft.

Groundwater in the area is recharged by the Old River, which has a 100 year flood elevation of +2.4 m (+8 ft); however, the river level is typically between about elevation +0.3 m (+1 ft) and +1.5 m (+5 ft). The ground surface elevation on Victoria Island and Byron Tract is approximately -2 m (-10 ft), and groundwater levels are typically no more than a meter or two below the ground surface.

ACCESS SHAFT DESIGN

Design Requirements

Based on the space required to launch and receive the microtunnel boring machine (MTBM), the jacking shaft was designed with a finished inside diameter of 8.2 m (27 ft), and the receiving shaft was designed with a finished inside diameter of 5.5 m (18 ft). The finished depths of the jacking and receiving shafts were approximately 27.5 m (90 ft) and 21 m (70 ft), respectively.

The Contract Documents required that the shafts be watertight with a maximum permissible inflow of 10 gallons per minute. Large scale dewatering of the site was not permitted due to concerns about consolidation settlement that would occur as a result of the reduction in pore pressure caused by the dewatering.

The GBR anticipated that the jacking shaft would be constructed “in the wet” using a caisson, or possibly, by a large diameter bore. In the wet construction was anticipated due the potential for the high groundwater table to destabilize the permeable soil layers located below the bottom of the shaft. During construction CCWD accepted the design team’s proposal to temporarily depressurize the permeable soils below the shaft bottom for the last portion of the excavation using deep wells so that the shaft work could be completed in the dry. The temporary depressurization was successful, and the work was completed without causing problematic settlement.

Secant piles, a slurry wall, sheet piles, and a large diameter bore were identified in the GBR as potentially feasible methods of constructing the receiving shaft. The competent, low permeability soil located below the bottom of the receiving shaft was not believed to be susceptible to heave or piping so excavation could be completed in the dry.

The design groundwater table at both shafts was specified as the 100-year flood elevation of the Old River: +2.4 m (+8 ft). This criterion required that the watertight lining of the receiving shaft extend a significant distance above the ground surface.

Soil-Cement Compression Ring

Malcolm Drilling proposed that primary initial support for both shafts consist of a series of overlapping soil-cement panels to form a pre-installed compression ring structure as an alternate to the shaft shoring methods discussed in the GBR. The compression ring was designed to resist a combination of at-rest soil pressure, groundwater pressure and construction surcharge loading. During initial design it was anticipated that soil-cement compressive strengths of between 300 and 500 psi would be achievable. The required CSM panel thickness and overlap were evaluated based on the anticipated attainable panel plumbness tolerance. The minimum ring thickness was based on the “worst case” assumption in which alternate CSM panels diverged inward and outward at their maximum permissible plumbness deviation.

The initial designs were based on the use of 1 m (3.3 ft) by 2.8 m (9.2 ft) CSM panels with a specified soil-cement compressive strength of 3,100 kPa (450 psi). The design of the shallower receiving shaft utilized a total of twelve panels to form a 6.4 m (21 ft) inside diameter compression ring. Two additional panels were planned on the outside of the compression ring at the tunnel penetration location. The jacking shaft compression ring design consisted of a total of thirty panels in a double ring configuration (i.e., an inner ring with 14 panels

and an outer ring with 16 panels) with an inside diameter of about 9 m (29.5 ft).

Test Program & Modified Design

A test program comprised of nine full-depth test panels was completed prior to the start of shaft construction in order to verify design and constructability requirements for strength, panel alignment and the mixing process. The test program was carried out near the receiving shaft location on Victoria Island.

Grout injection rates in the individual test panels varied from 458 L/m^3 to 936 L/m^3 (treated soil volume). Wet-grab samples were collected from depths of 8 m (26 ft) and 16 m (52 ft) in each test panel. Compressive strength tests on the various grout injection rates ranged from 4,150 kPa (600 psi) to 12,400 kPa (1,800 psi) at 14 days and 5,500 kPa (800 psi) to 17,900 kPa (2,600 psi) at 28 days. Based on the compressive strength tests from the test program, a grout injection rate of 500 L/m^3 of treated soil was selected for the production panels.

The test program was also used to verify that a two-phase system could be employed, whereby cement is not used on the downstroke. For this application, Malcolm Drilling used only water on the downstroke to fluidify the in-situ soils and then cement grout only on the upstroke. The test program helped conclude that a two phase system was viable, and that the in situ soils were sufficiently clayey to render the use of bentonite unnecessary to lower the permeability of the wall.

Based on the test program, it became evident that the CSM process was capable of producing substantially stronger soil-cement than had been assumed in the initial shaft designs. The receiving shaft design was revised based on a design compressive strength of 5,150 kPa (750 psi), which allowed the compression ring to be constructed using thirteen, smaller 0.76 m (2.5 ft) by 2.4 m (7.9 ft) panels. Three additional panels were used at the tunnel penetration location. As shown in Figure 1, the jacking shaft compression ring was reconfigured with only fourteen 1.0 m (3.3 ft) by 2.8 m (9.2 ft) panels in a single row with a design compressive strength of 8,250 kPa (1,200 psi). Three additional panels were installed on the outside of the compression ring in the MTBM jacking reaction location. A section view of the jacking shaft is shown in Figure 2.

Shotcrete Lining

Due to the fact that this was the first project in the United States where unreinforced CSM panels were being used to create a compression ring structure, the design team decided that it would be prudent to install supplemental ground support during excavation in the deeper portions of the shafts where the soil-cement compression ring would be more highly stressed. High-early strength, wire mesh reinforced shotcrete, installed in a top-down manner, was used for this purpose. Due to uncertainty about how the earth and water loads might be shared by the soil-cement and shotcrete compression rings, each system was designed with sufficient capacity to resist the entire external design load on its own. The shotcrete thickness increased with depth to accommodate the increasing external pressures acting on the shaft.

Uplift Resistance At Bottom Of Shaft

The shotcrete lining also served to hold down the cast-in-place, reinforced concrete seal slabs that were constructed at the base of each shaft. The shotcrete lining did not have sufficient weight on its own to resist the net uplift force acting on the slab so the remainder of the load was shed to the soil-cement panels through adhesion between the shotcrete and the soil-cement. This approach eliminated the need for tiedown anchors that would have otherwise been required to hold down the seal slabs.

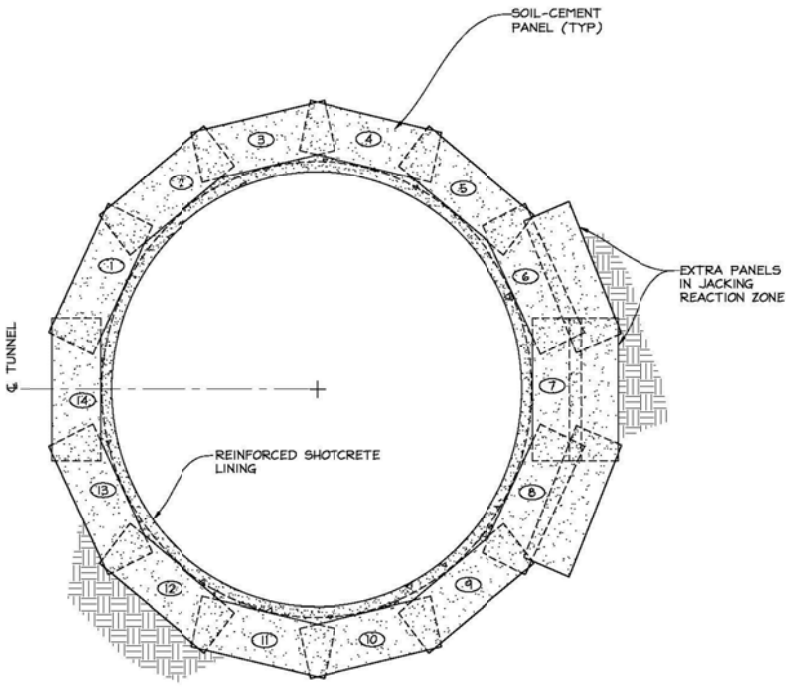

Figure 1: Jacking shaft plan view

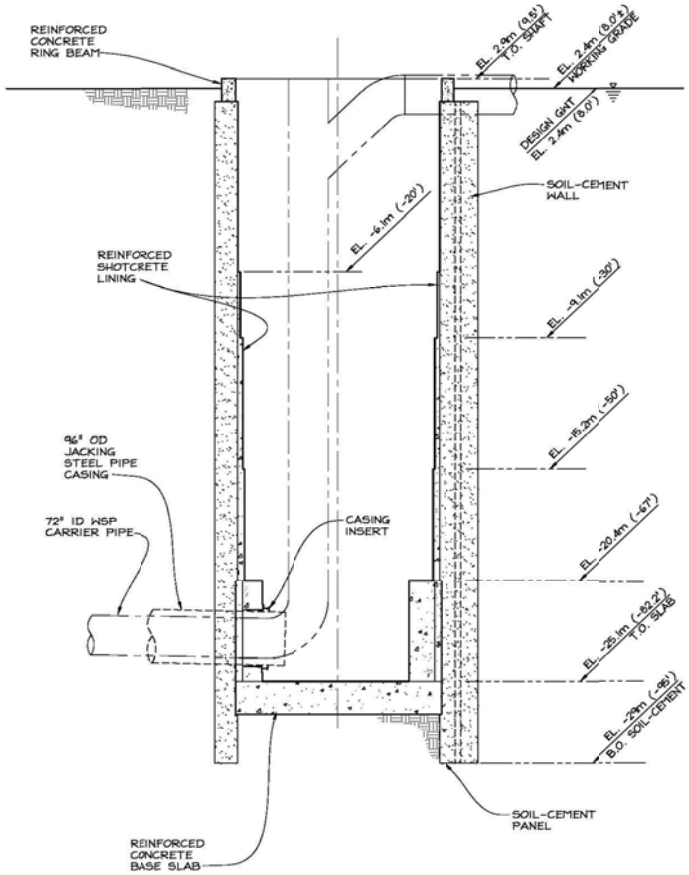

Figure 2: Jacking shaft cross section

Other Shaft Elements

In addition to the seal slabs, more heavily reinforced shotcrete structures were constructed at the bottom of each shaft to accommodate the tunnel penetrations and the MTBM jacking forces. The tunnel eyes (break out and break in locations) were reinforced in a similar manner at each shaft. Vertical "deep beams" were installed to either side of the unreinforced tunnel eye. These deep beams were designed to transfer the shaft loads to a ring beam above the tunnel eye and the seal slab below the tunnel eye.

The thrust block at the jacking shaft was contractually-required to be designed to resist 2,540 tons of jacking force (twice the maximum jacking force that could be applied by the MTBM jacking system) and spread it over a sufficient reaction area. A heavily reinforced shotcrete block, in combination with the extra external CSM panels, safely distributed the load.

As mentioned above, the watertight lining of the receiving shaft had to be extended about 6 m (20 ft) above the ground surface to accommodate the 100 year flood water level. A corrugated steel "Multi-Plate" lining with interior shotcrete for stiffening was used for the shaft extension.

CONSTRUCTION

The CSM Method & Equipment

The CSM (Cutter Soil Mixing) system is a modified trench cutter "Hydro Mill" type machine, as used in modern slurry wall construction. Unlike conventional soil mixing techniques that utilize end mixing mechanical tools depending on mechanical mixing between shear blades in axial motion, the CSM system utilizes a set of milling wheels working in the vertical plane. This mechanical action shears the soil into small particles and blends it with the injected grout or other cutting fluids into a homogeneous matrix.

The CSM machine has a very stiff non-rotating Kelly bar attached to a base machine. This stiff Kelly, coupled with the CSM's inclinometers, allow the cutter head to be steered in the "X" axis by altering wheel speed and in the "Y" axis by the base machine's parallelogram. This telemetry control allows panels to be cut to the required alignment, with real–time monitoring and recorded by the on-board computerized QC system.

All processes are controlled by an intensive quality assurance program. All process-specific production and plant-specific operating data are visualised throughout the construction phase and stored for subsequent documentation and evaluation. Information presented includes penetration rates, alignment, and slurry injection rates and volumes.

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Some of the advantages of the CSM method are that it uses in-situ soil as construction material and that high compressive strengths can be achieved due to the effective blending of all cement particles within the soil matrix. The process is also capable of being advanced into soft rock formations and does not induce vibrations during construction.

Shaft Construction

The receiving shaft was the first shaft constructed due to the fact that it was less than 100 m (300 ft) from the site of the test program. A Bauer RTG 25 with a 0.76 m x 2.4 m (2.5 ft x 7.8 ft) BCM 5 CSM unit was used for the receiving shaft, and a larger Bauer BG 40 with a 1.0 m x 2.8 m (3.3 ft x 9.2 ft) BCM 10 CSM unit was used for the jacking shaft. Slurry from the

CSM process was contained in trenches and a MAT HP-50 pump was used to pump the slurry to a temporary storage basin. From there, the slurry was relocated to the final disposal site on another part of the project using vacuum trucks.

A survey crew was on site each day of production panel work to provide corner layout for the individual panels to ensure that the panels were placed in the correct location with the correct overlap.

Immediately following panel installation, a dewatering well was installed within the shaft. Once the perched water within the clays and sands was pumped out, the well did not produce any additional water. Additionally, a reinforced concrete ring beam was installed at the top of the shaft. The ring beam served to extend the panels from the trench they were constructed in to the level of the surrounding grade.

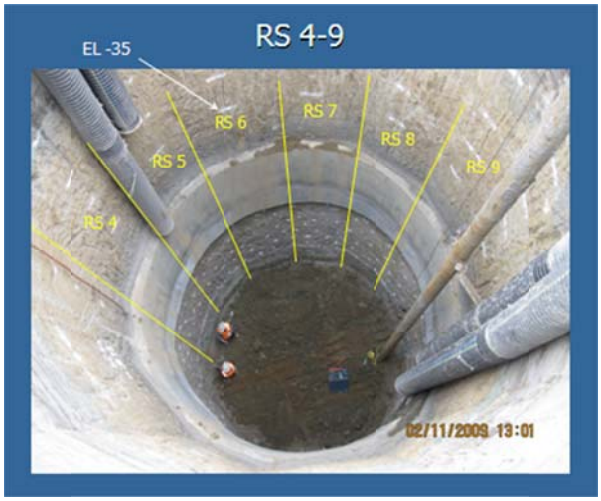
Wet-grab samples were collected from depths of 8 m (26 ft) and 16 m (32 ft) in each panel. Within 7 days, compressive strengths averaged in excess of 6,900 kPa (1,000 psi) which allowed excavation to proceed. The high compressive strength also allowed for a design revision that eliminated the need for shotcrete in the upper 9.1 m (30 ft) of the shaft.

The top 4.5 m (15 ft) of the shaft was excavated with a 25 T (27 t) excavator. A 40 T (45 t) long reach excavator was used to excavate the next 8 m (25 ft) of the shaft. A clam-shell attached to a 90 T (100 t) crane along with a mini-excavator lowered into the shaft were used to excavate the remainder of the shaft. During excavation, a survey crew was brought in to take measurements at the face of the CSM panels. This information was correlated with the shaft design and production reports to ensure that the compression ring was intact.

Installation of the shotcrete lining began 9.1 m (30 ft) below the top of the shaft and was installed in 1.5 m (5 ft) lifts to the top of the reinforced concrete base slab.

Construction of the jacking shaft started after completion of the CSM panels at the receiving shaft. Wet-grab samples were obtained at depths of 14 m (46 ft) and 28 m (92 ft) within each panel.

Immediately following panel installation at the jacking shaft, a dewatering well was installed within the shaft. Similar to the receiving shaft, the well failed to produce any water after the perched water within the clays and sands were pumped out.



CSM

Excavation methods for the jacking shaft were similar to those employed at the receiving shaft. The shotcrete lining started 9.1 m (30 ft) below the top of the shaft. Excavation and shotcrete proceeded on an approximate 3-day cycle for every 1.5 m (5 ft) lift. A survey crew was once again used to take measurements at the face of the CSM panels as the excavation proceeded. This information was compared to the verticality data from production reports to verify correct panel location and overlap.

During excavation, 100 mm (4 in) horizontal cores were taken from each panel at multiple elevations. Compressive strength data from the cores were compared to compressive strength data from the wet grab samples. This information was used to verify that the strength of the in-situ CSM panels met the design requirements.

After initial shotcrete was completed to the top of the base slab, the base slab was placed, followed by the reinforced shotcrete jacking pad. Prior to the start of microtunneling, grouting was performed at the construction joints between the CSM panels and the shotcrete lining in order to ensure that the microtunneling penetration was watertight.

CONCLUSIONS

Cutter Soil Mixing (CSM) was successfully used to construct two microtunnel access shafts in difficult soil conditions. A two phase system was used, where only water was injected in the downstroke, and cement slurry was injected on the upstroke. This resulted in most of the injected cement staying in the ground, resulting in high unconfined compressive strengths of 8,300 kPa (1,200 psi) (mean, at 28 days) at the jacking shaft. The high unconfined compressive strengths allowed the design team to reduce some of the supplemental shotcrete lining, and eliminated a double row of panels at the jacking shaft.

CSM allowed construction of the shafts to proceed in the dry, without the need for significant dewatering to complete the shaft construction.

REFERENCES

Jacobs Associates (2008) Geotechnical Baseline Report, Microtunnel and Shafts, Alternative Intake Project, Contra Costa Water District. May 2008